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The Effectiveness of Infrared Suppression Techniques in Reducing the Vulnerability of the F-4 Aircraft to the ATOLL Missile

[Unclassified Title]

H. TOOTHMAN, R. LISTER, AND C. LOUGHMILLER

Airborne Radar Branch
Radar Division

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MEMORANDUM

SUBJECT: The Effectiveness of Infrared Suppression Techniques in Reducing the Vulnerability of the F-4 Aircraft to the ATOLL Missile

Background

(S) The ATOLL is the most frequently observed heat-seeking air-to-air missile in Communist-controlled countries such as North Vietnam. It is an accurate copy of the early Sidewinder, and data which permit its accurate simulation are readily available. This report is the fourth in a series describing countermeasures for the ATOLL.

Findings

(S) A reduction of the infrared (IR) radiation of the F-4 aircraft can reduce ATOLL launch zones. However the only technique which caused a significant reduction relied on a dispersive cloud of TiO_2 particles to scatter the IR radiation.

R & D Implications

(S) Further studies of different scattering or absorption materials and dispensing techniques are warranted because of their potential effectiveness for aircraft protection. Improved cooling of engine parts and tailpipe liners beyond that studied at this time may make significant reductions in ATOLL launch zones.

Recommended Action

(S) The development of materials and dispensing techniques for IR scattering or absorption should be pursued with a view to decreasing the ATOLL launch zones. Concurrently, trade-off studies should be undertaken to determine the costs of engine and tailpipe cooling versus active IR countermeasures power requirements. The effects of each technique upon engine and aircraft performance should be studied thoroughly.

Clair M. Loughmiller
Tactical Analysis Section
Airborne Radar Branch

ABSTRACT (S)

Five IR suppression techniques were examined to determine their effectiveness in reducing the vulnerability of the F-4 aircraft to the ATOLL missile. Two of these techniques, both using IR dispersive clouds, significantly reduced ATOLL performance. ATOLL launch zones are given for three non-maneuvering and four maneuvering tactical conditions.

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I. INTRODUCTION

(C) The ATOLL (AA-2), a Soviet copy of the Sidewinder missile, poses a significant threat to U.S. aircraft. One way of reducing the ATOLL threat is to reduce its launch zone by reducing the target aircraft's IR radiation in the ATOLL seeker bandpass. This report is a study of the effectiveness of techniques for reducing the IR output of the F-4 aircraft at military power.

(S) Several problems must be considered when attempting to decrease the vulnerability of an aircraft to a missile. At altitudes below 15K feet the ATOLL is aerodynamically limited while engaging an F-4 on military power. In this case, to reduce the ATOLL launch zone by reducing IR output of the aircraft, the IR output must first be reduced to where the IR limit equals the aerodynamic limit. Further reduction of IR output must now be made to reduce the ATOLL launch zone. The effect of these further reductions will follow the inverse square law, i.e., a four-fold reduction of IR energy output is required to reduce ATOLL range by a factor of two.

(U) A digital simulation of the ATOLL has been used to determine the countermeasures effectiveness of IR reduction techniques developed by General Electric (GE). The IR signatures estimated by GE are used in the simulation. The results of many simulated trajectories are combined to determine launch zones for the ATOLL for each IR signature supplied by GE.

II. COMPUTER REPRESENTATION

(C) A four-degree-of-freedom model of the F-4 aircraft and a six-degree-of-freedom model of the ATOLL have been constructed at the Naval Research Laboratory (NRL). The thrust, drag, and lift characteristics of the F-4 were included to assure realistic simulation of maneuvers. The IR signature of the F-4, atmospheric attenuation formulas, and ATOLL detector sensitivity measurements were used to develop the IR signal model. ATOLL tracking error data were combined with a Sidewinder 1A tracking model for the missile guidance characteristics. Sidewinder 1A gas servo performance data are included in the guidance and autopilot model. Tables of aerodynamic moments, along with normal and axial forces, for the ATOLL are used in the computer program to calculate the missile response. Data used in the development of the missile model were supplied by Naval Weapon Center (NWC), China Lake. A full description of the missile model and the F-4 aerodynamic model is found in (1).

III. IR SUPPRESSION MODELS

A. Suppression Techniques

(S) General Electric (Evendale, Ohio) has made theoretical studies and ground measurements of possible IR suppression retrofits to the J-79-10 and J-79-17 engines used in the F-4. The effects of centerbody cooling, tailpipe cooling, and fuel and oil cloud generation on the IR signal of the J79 are described in (2). Subsequent to (2), GE suggested that a titanium dioxide (TiO_2) cloud would be highly effective in reducing the J79 IR emissions. Also subsequent to (2), GE revised their estimate of practical component cooling from 1200°R to 1400°R and revised the IR data accordingly. These revised IR signature estimates, as well as an estimate of the signature through a TiO_2 cloud, were used in this study.

(S) Five suppression techniques were selected for comparison with the standard (unmodified) engine. The models used in this study are 1) the unsuppressed J79, 2) a "7808" oil cloud, 3) centerbody and tail-pipe cooled to 1400°R, 4) tail-pipe only cooled to 1400°R, 5) center-body only cooled to 1400°R, and 6) centerbody and tailpipe cooled to 1400°R plus a titanium dioxide cloud. Model 1 was chosen as a reference for each of the techniques. Model 2 was chosen because it represents a minimum of modification, development, and weight penalty. Models 3, 4, and 5 are covert techniques. Model 6 represents the best technique for IR suppression used in this study.

B. Computer Model

(S) The IR signatures used in the computer model are given in Table 1. Since the data supplied by GE, (2), were for only one J79 engine, it was assumed that the total F-4 emission would be twice that for a single engine. Thus the data in Table 1 are twice the values of IR radiant intensity given by GE. Since GE calculations are for the total radiant intensity in the 1.7 to 2.95 micron band, it is necessary to reduce these values during the simulation to account for the ATOLL's spectral response in this band. Calculations show that the ATOLL sees 65% of the total energy of a blackbody in the 1.7 to 2.95 micron band at normal J79 tailpipe temperature. The 35% signal loss was applied to the F-4 signatures of Table 1.

(U) Atmospheric attenuation of the signal is also based on normal tailpipe temperature blackbody spectral characteristics. The band pass of the ATOLL seeker is broken into 0.1 micron intervals. This enables a more accurate calculation of how tailpipe energy in the IR spectrum is attenuated as a function of range. The calculations, based upon a blackbody at 950°K, were performed at several ranges and altitudes. The loss in decibels is given in Table 2. The assumption of normal

tailpipe temperature spectral response was made necessary because the spectral characteristics of the various suppression techniques were not available. No tailpipe shielding effects were used in this study.

IV. ATOLL PERFORMANCE

A. Non-Maneuvering F-4

(C) The non-maneuvering launch envelopes for the ATOLL engaging an F-4 aircraft with 3 altitude-speed combinations are given on Figures 1, 3, and 6. There are no arbitrary restrictions on the envelope. That is, if a missile is launched within the envelope it will come within 25 feet of the center of mass of the F-4. In particular, no criterion is used to judge whether or not the enemy pilot can tell if the ATOLL is capable of tracking the F-4. Under certain conditions an initial signal-to-noise ratio of less than 2 is sufficient for the ATOLL to guide successfully. There is some question whether the pilot can detect such signal against typical background noise. Thus the overall system effectiveness envelopes may be significantly smaller than the missile envelope presented here.

(S) The envelopes on Figure 1 show that at 5K feet altitude the ATOLL is essentially aerodynamically limited. Thus, only at large angles off the F-4 tail (where the ATOLL is normally IR energy limited) are there significant differences shown for the various suppression techniques. The situation is much the same at 15 K feet altitude except that the oil drop cloud has a marginal effectiveness. At low altitudes only the TiO_2 cloud significantly reduces ATOLL launch envelopes. The reductions of the launch zone area due to the TiO_2 cloud as shown on Figures 1 and 3 are about 75% and 85% respectively.

(SNF) At 30K feet, as shown on Figure 6, the oil drop cloud is fairly effective and the TiO_2 cloud is very effective. The component cooling techniques were not significantly effective in the non-maneuvering target situations. Thus the moderate cooling assumed in the IR models used in this study does not provide a useful covert IRCM technique. However, such cooling may be useful in conjunction with pulsed jammers, since it permits lower power IR transmitters. The TiO_2 cloud is very effective if it can be generated before the ATOLL is launched. This implies either a technique to warn the F-4 when an ATOLL attack is imminent, or a continuous generation of the cloud. The cloud is likely to be highly visible in daylight and thus is unsuitable for use except when the F-4 is under ATOLL attack.

B. Maneuvering F-4

(SNF) As shown in Figures 2, 4, 5 and 7, the ATOLL launch zones are reduced significantly by maneuvers of the F-4. However, only the TiO_2 cloud significantly reduces the size of the maneuvering F-4

ATOLL launch envelopes under all conditions studied. The oil cloud is effective at 30K feet altitude but relatively ineffective at lower altitudes. The use of TiO_2 in air combat maneuvering situations may be valuable. Although the cloud trail would be useful to the enemy for acquisition and tracking, it is possible that he might not be able to press a successful attack into the more restricted launch zones.

V. CONCLUSIONS

1. (S) The component-cooling models which were studied are ineffective ATOLL countermeasures.

2. (S) A cloud of TiO_2 particles has significant countermeasure potential.

VI. RECOMMENDATIONS

1. (C) Studies or tests to determine the minimum signal that may be detected by the pilot of the ATOLL aircraft should be initiated.

2. (S) Instrumented flight tests to determine the IR suppression characteristics of TiO_2 (or similar) clouds should be initiated.

3. (SNF) Detailed studies to determine the usefulness of component cooling in conjunction with pulsed IR jammers should be initiated.

REFERENCES

1. H. Toothman, C. Loughmiller, and R. Lister, "The Effect of F-4B Maneuvers on ATOLL (AA-2) Performance," NRL MR 1989, Secret Noforn, 1969.

2. R.E. Latta, T. Loftus, and C.M. Stanforth, "Interim Status Report on the General Electric J79 IR Suppression Program," R69AEG 415, Secret, October 1969.

TABLE 1 (S)

F-4 Infrared Radiant Intensity (twice J79 Intensity)
in 1.7-2.95 Micron Band (watts/steradians)

Altitude	Angle off engine axis deg.	IR Model Number 1	2	3	4	5	6
5K ft	0	594	44	448	594	448	16
	5	820	54	698	818	690	22
	10	876	58	805	845	839	26
	25	494	152	292	292	494	45
	45	90	130	90	90	90	65
	60	40	40	40	40	40	20
	90	20	34	20	20	20	17
15K ft	0	642	48	474	642	476	18
	5	876	58	733	874	733	24
	10	930	60	857	902	871	28
	25	516	158	306	306	516	47
	45	56	130	56	56	56	65
	60	44	40	44	44	44	20
	90	20	34	20	20	20	17
30K ft	0	526	40	385	526	385	15
	5	724	48	604	723	605	20
	10	772	50	716	747	742	24
	25	412	126	245	245	411	38
	45	42	130	42	42	42	65
	60	32	40	32	32	32	20
	90	20	34	20	20	20	17

Table 2 (U)

Blackbody (~850°K) IR Atmospheric Attenuation in the ATOLL Bandpass (decibels)

Altitude (K ft)	Range (ft)				
	1,000	3,000	6,000	12,000	24,000
0	2.33	3.66	4.15	4.51	4.91
10	1.70	2.45	2.95	3.51	3.99
20	0.89	1.32	1.70	2.22	2.69
30	0.35	0.65	0.90	1.05	1.41
40	0.14	0.28	0.42	0.57	0.73
50	0.01	0.14	0.21	0.28	0.42
60	0.00	0.01	0.07	0.21	0.28
70	0.00	0.00	0.01	0.07	0.14

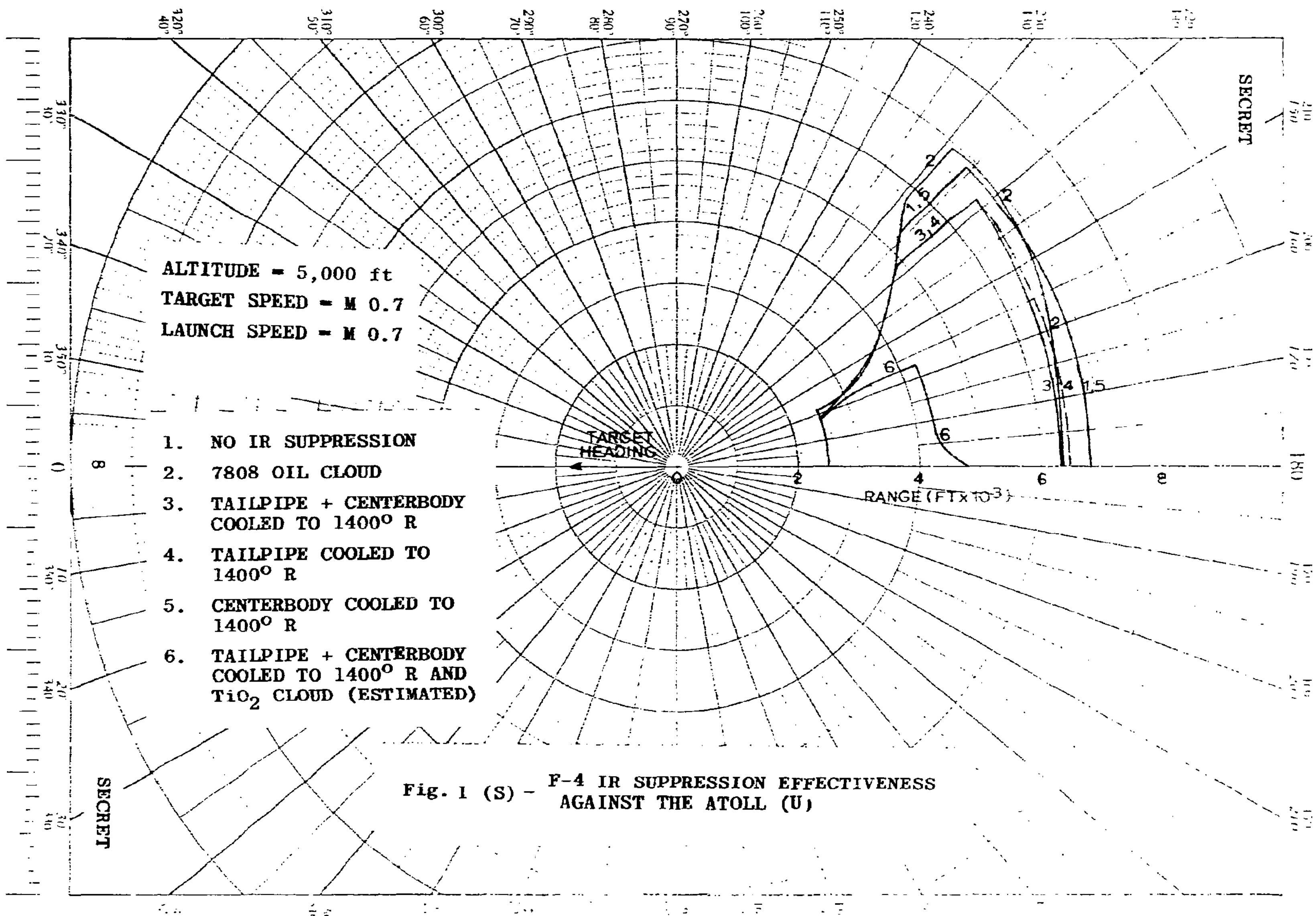

Fig. 1 (S) - F-4 IR SUPPRESSION EFFECTIVENESS AGAINST THE ATOLL (U)

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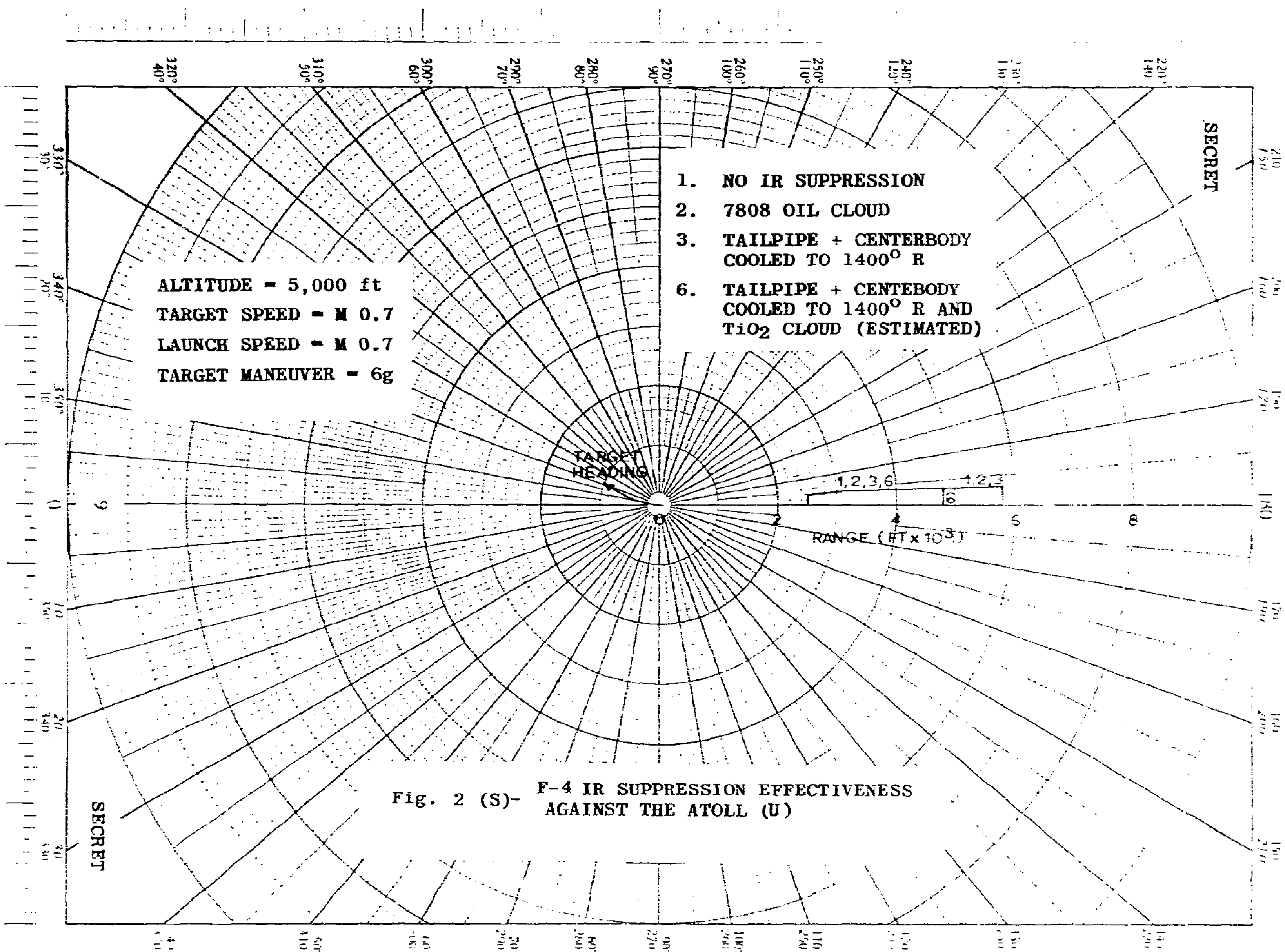

Fig. 2 (S)- F-4 IR SUPPRESSION EFFECTIVENESS AGAINST THE ATOLL (U)

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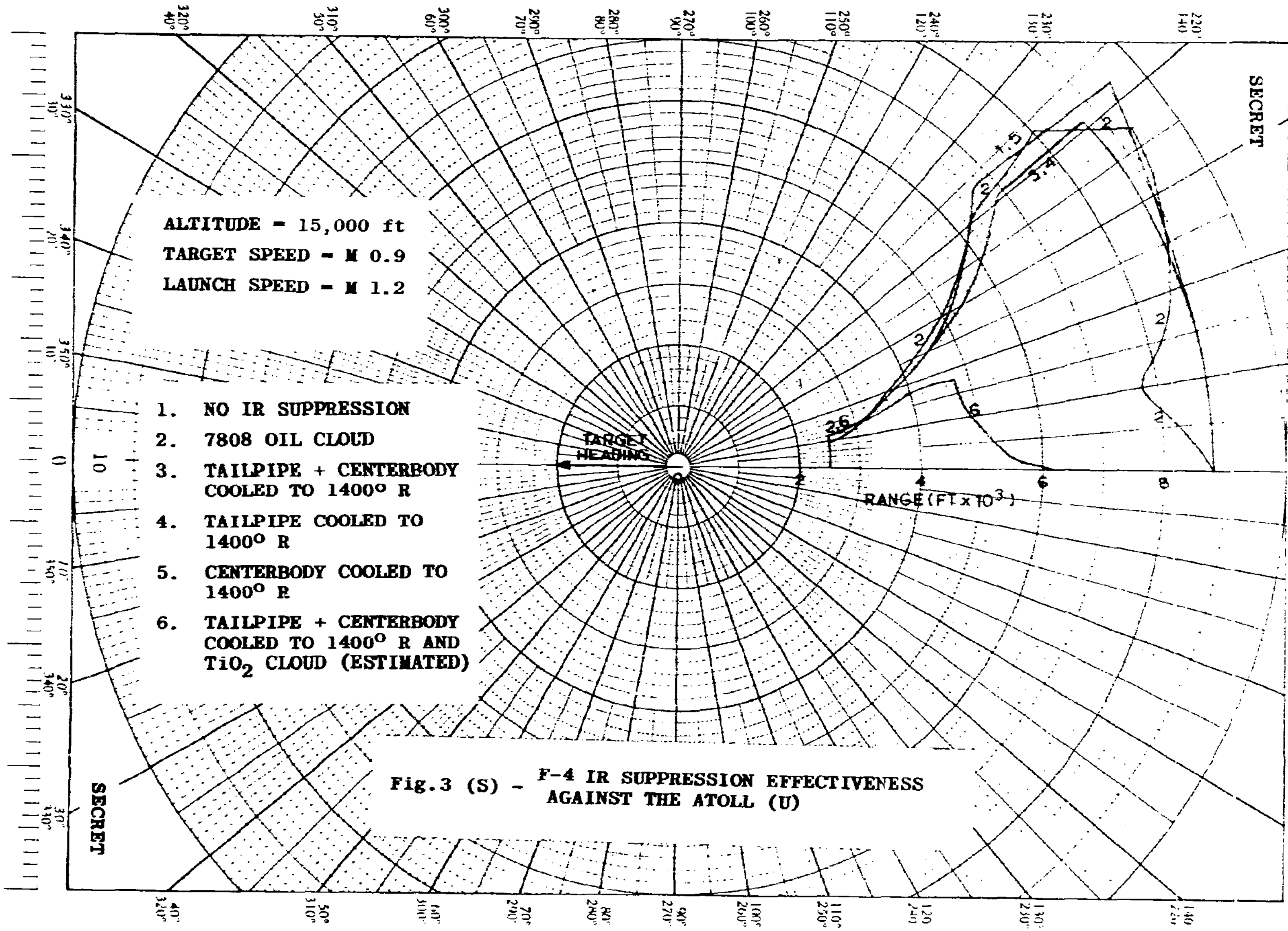

Fig.3 (S) - F-4 IR SUPPRESSION EFFECTIVENESS AGAINST THE ATOLL (U)

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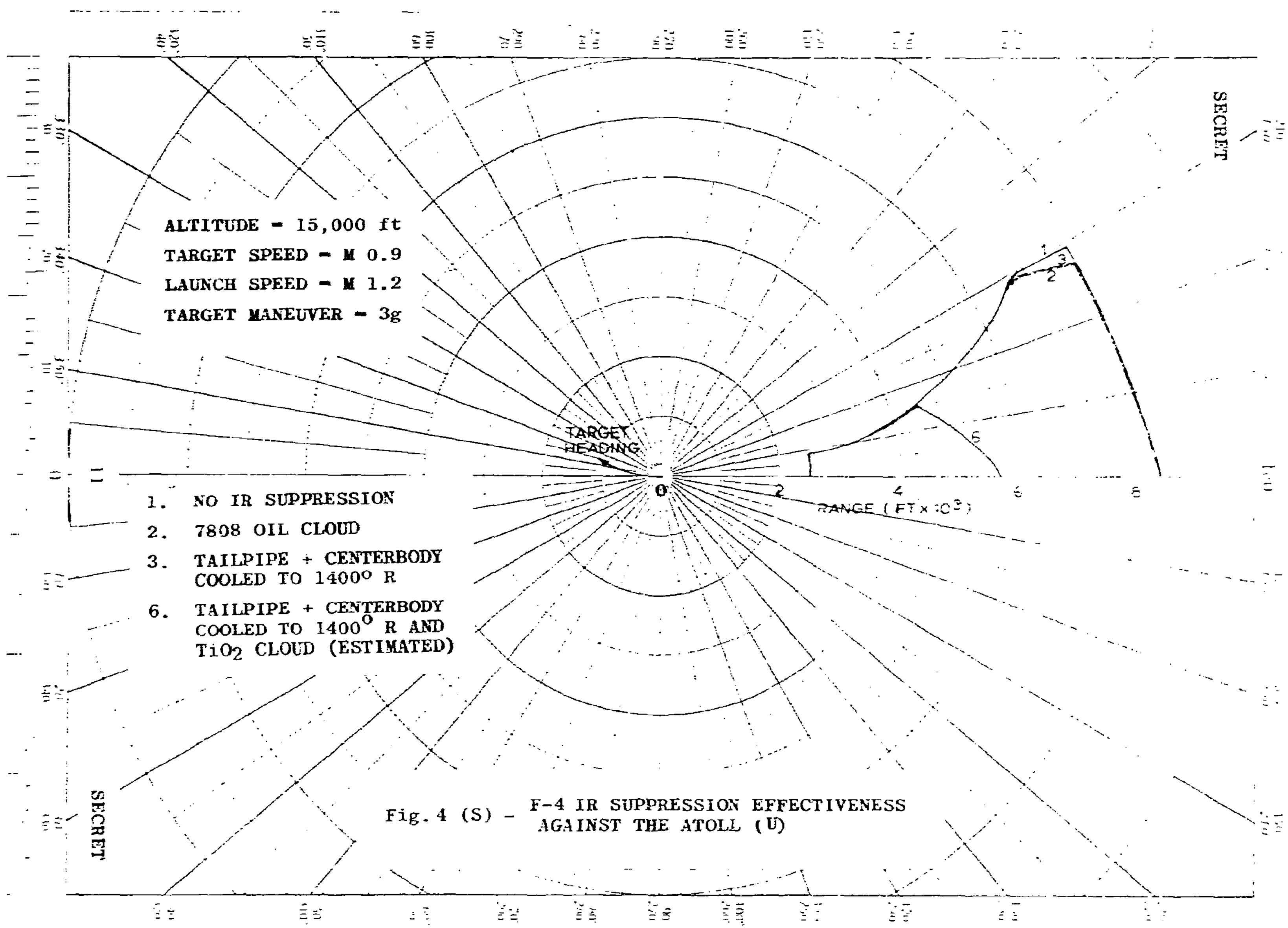

Fig. 4 (S) - F-4 IR SUPPRESSION EFFECTIVENESS AGAINST THE ATOLL (U)

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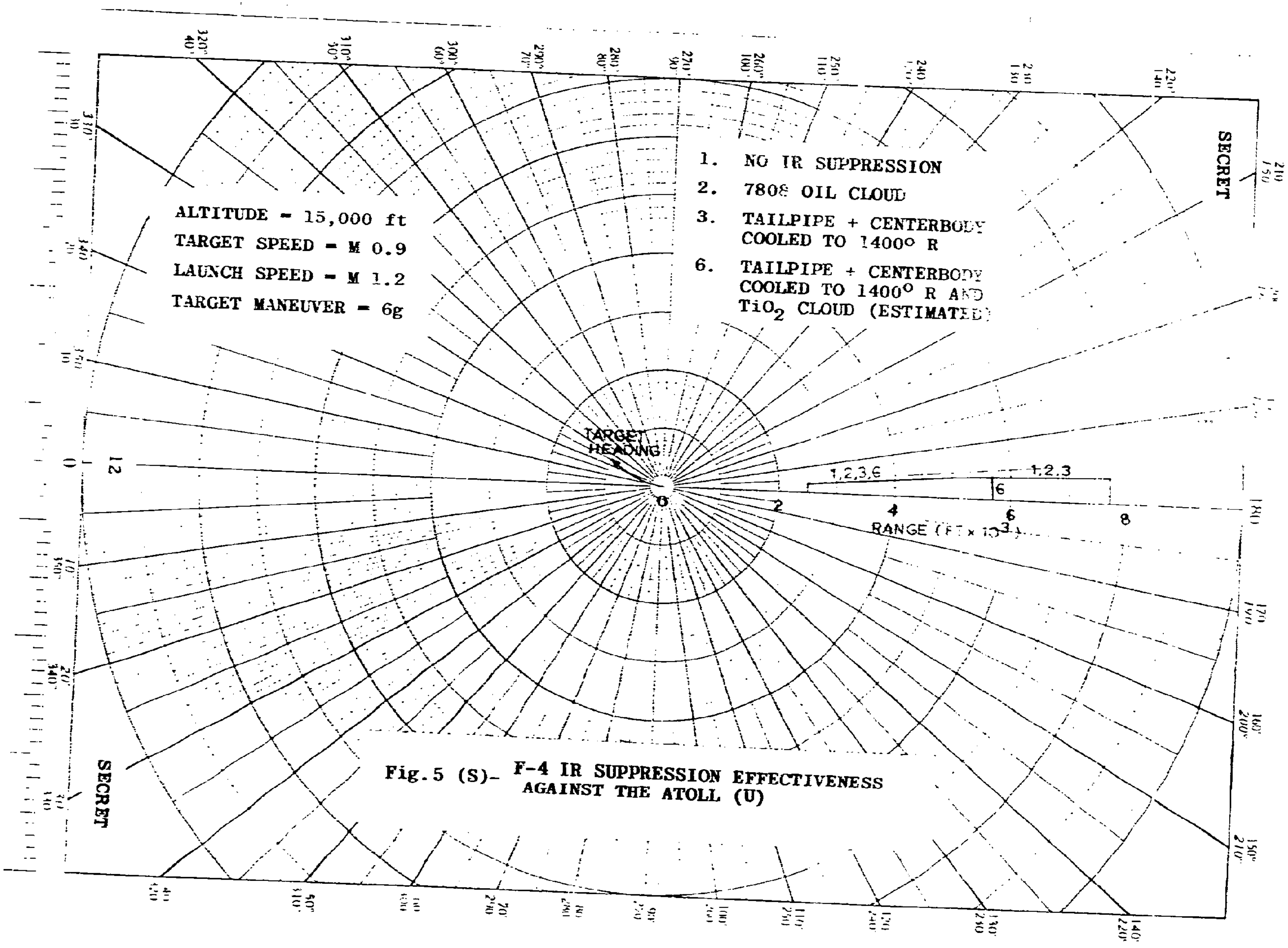

Fig. 5 (S)- F-4 IR SUPPRESSION EFFECTIVENESS AGAINST THE ATOLL (U)

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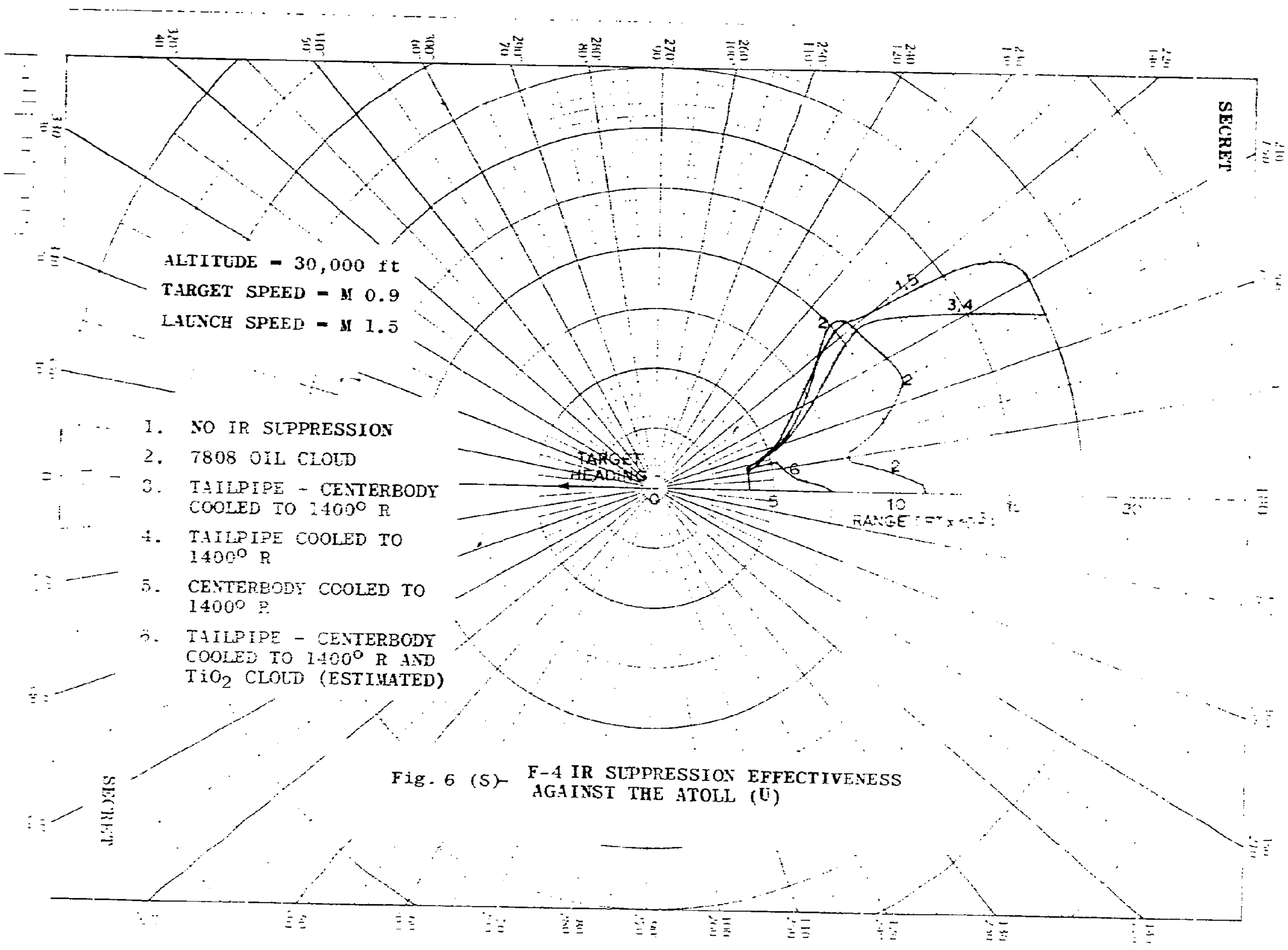

Fig. 6 (S)- F-4 IR SUPPRESSION EFFECTIVENESS AGAINST THE ATOLL (U)

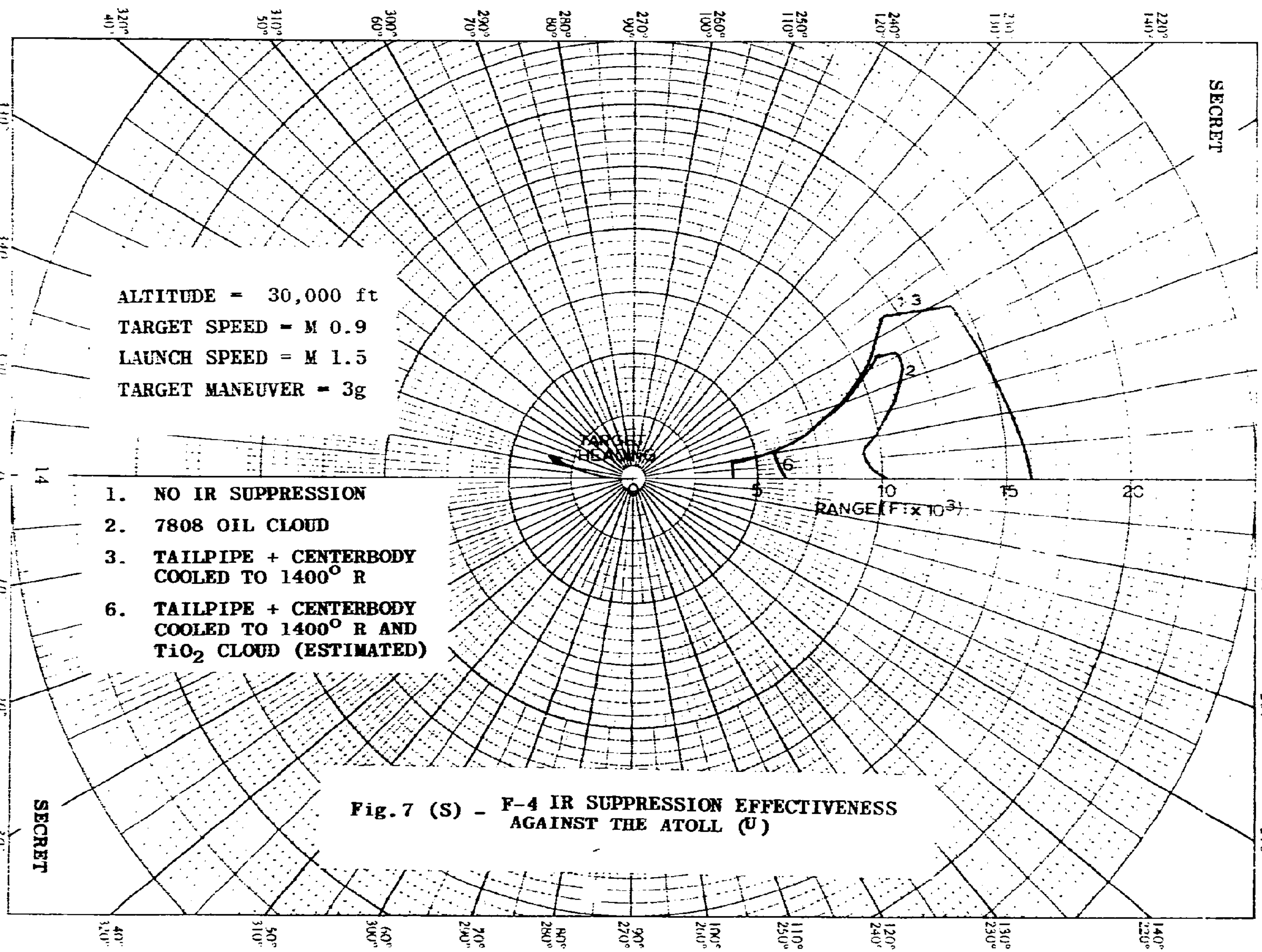

Fig. 7 (S) - F-4 IR SUPPRESSION EFFECTIVENESS AGAINST THE ATOLL (U)

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